Regional Lateral Zoning of the Mesozoic to Early Tertiary Endogenic Lead-Zinc and Copper Deposits in East Asia and Its Geological Background, with Some Comments on the Drifting of the Japanese Islands*

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Abstract: Regional lateral zoning of the late Mesozoic to early Tertiary endogenic lead-zinc and copper deposits is known in Japan and Korea. The lead-zinc deposits are distributed on the Japan Sea side and the copper deposits on the Pacific Ocean side of Japan. The lead-zinc deposits occupy the northern half and the copper deposits the southern half of Korea. Sikhote-Alin Province may belong to the lead-zinc zone. According to the latest geological data available, a similar regional lateral zoning of the Mesozoic endogenic lead-zinc and copper deposits is recognizable in the area south of the Yangtze River in China. The lead-zinc deposits occupy the western part and the copper deposits the eastern part of that area. Moreover, a similar tendency toward zoning of ore deposits may be present in Southeast Asia, although the data available are scarce.

Deformation of the continental plate, due to subduction of the oceanic plate during Mesozoic to early Tertiary time may be one of the most important causes of the lateral zoning of ore deposits in the areas cited. As the result of this deformation, fracturing and following generation of magma took place within the continental plate. The lead-zinc and copper deposits were formed in close genetic connection with the granitic magma originating from the more acidic upper portion and the more basic lower portion, respectively, of the continental plate.

Generally speaking, the gentler the inclination of the subduction zone, the broader the copper zone tends to become. The copper zone south of the Yangtze River in China may be one of the best examples of this broadening in East Asia. The zone has a width of more than 500 km. In contrast, in the Burmese-Malayan peninsula, the inclination of the Mesozoic subduction zone may be large; no extensive copper zone is known in that area, and lead-zinc mineralization is poor. Drifting of the Japanese Islands is estimated to have begun about 50 Ma ago.

1. Introduction

As is well known, the vertical zoning of ores can be observed in most replacement and vein-type deposits. It is of course very important to recognize properly this fact, together with the amount of post-ore erosion, at the time of prospecting of an individual ore deposit.

For more than 40 years, since 1937, the writer has been studying many of the contact-metasomatic and vein-type deposits of Japan and Korea. According to the results obtained from the writer's study of these deposits, regional lateral ore zoning is more evident than vertical zoning, so far as the Mesozoic to early Tertiary endogenic lead-zinc and copper deposits in East Asia are concerned, and it may be most important to keep this fact in mind if one intends to make an effective prospecting of such deposits in this region.

In this paper, a description of the regional lateral zoning of these deposits in Japan and Korea, together with some other examples in East Asia precedes a discussion of the mechanism of formation of this zoning and of
the source of the ore-forming elements. Some comments on the drifting of the Japanese Islands will also be presented.

Regional Lateral Zoning of the Ore Deposits

All the endogenic deposits have their own vertical extent, from top to bottom, though it is not large. The maximum value is about 1,000 m. Generally speaking, it is not always easy to know exactly the vertical extent of ore deposits, owing to the uncertain extent of post-ore erosion and the limited extent of vertical exploitation of the deposits. However, in many mines of Japan and Korea, the exploitation of ore deposits is carried out to a depth of several hundreds meters below the surface with maximum vertical extent of more than 1,000 m, and it is rather easy to know the bottom or the lowest limit of the contact-metasomatic deposits in these countries. Under these conditions, a discussion of the zoning of ore or ore deposits can be presented with considerable accuracy.

1. Regional lateral zoning of the ore deposits in the Far East, including Japan, Korea and Sikhote-Alin Province, U.S.S.R., and the drifting of the Japanese Islands

The lead-zinc deposits of the Ulchin mine are good examples of the contact-metasomatic deposits in Korea (Miyazawa, 1977). The location of the mine is shown in Fig. 1. The deposits occur mainly in the lower Paleozoic limestone near the contact with the Bulguga granite of late Cretaceous to early Tertiary age. The deposits terminate in the granite on the Central adit level, the lowest level about 400 m below the surface, and no other deposits are known below this level. The ores consist mainly of sphalerite and pyrrhotite with a large amount of endomorphic garnet and epidote and the copper minerals such as chalcopyrite are very small in amount even at this level; that is, a copper-rich portion does not appear in the lower part of the lead-zinc deposits. In Korea, most of the metallic mineral deposits are formed in a close genetic relation with the Bulguga granite (Miyazawa,
Fig. 1 Regional lateral zoning of the late Mesozoic to early Tertiary endogenic lead-zinc and copper deposits in Japan and Korea (MIYAZAWA, 1977).

The lead-zinc deposits of the 1st Yeonhwa mine are developed in the northern end of Gyeongsanbugdo, Korea. The location of the mine is shown in Fig. 1. The mine is the largest lead-zinc mine in Korea; its monthly production is 60,000 tons. The deposits are of skarn type, occurring in the lower Paleozoic limestone, and are believed to be of Cretaceous age. The vertical extent of exploitation amounts to about 600 m, but no copper ores are known, even on the lowest level (MIYAZAWA, 1977).

Similar contact-metasomatic lead-zinc deposits of late Mesozoic to early Tertiary age are extensively developed in the northern part of Korea, especially in the Teabaecksan area and on the Japan Sea side of Japan. The deposits of both the Kamioka and the Nakatatsu mines are the representative ones in the latter (Fig. 1 and Table 1).

Some contact-metasomatic lead-zinc deposits of the Akatani-Iide mining district, Japan are also believed to be of Cretaceous age.

The deposits of the Kasagatake mine, Japan (Fig. 1) are high grade lead-zinc veins occurring in Cretaceous rhyolitic rock. They crop out at a height of about 2,100 m above sea level of Mt. Kasagatake (about 2,900 m above sea level), one of the peaks of the Japanese Alps. During the 2nd World War, the veins were exploited down to about the 1,400 m level, but copper ores did not appear even on this low level.

Similar lead-zinc veins are extensively distributed on the Japan Sea side of Japan and in the northern half of Korea (Fig. 1 and Table 1). Of course, vertical zoning of lead and zinc ores is well observed within both contact-metasomatic and the vein-type deposits described here.

As for the late Mesozoic to early Tertiary copper deposits, those of Kamaishi, Yaguki
and Kosung mines (Fig. 1 and Table 1) are good examples, the first two being major contact-metasomatic deposits in Japan and the last being one of the major vein-type deposits in Korea. With few exceptions, we can not find lead-zinc-rich portions in the upper part of these deposits. The ore deposits of the Kamaishi mine occur in the upper Paleozoic limestone and in porphyrite near the contact with the Cretaceous granite.

Similar copper deposits are extensively distributed on the Pacific Ocean side of Japan and in the southern half of Korea (Fig. 1 and Table 1). Thus, the regional lateral zoning of the late Mesozoic to early Tertiary endogenic lead-zinc and copper deposits, regardless of contact-metasomatic or vein occurrence, is clearly observed both in Japan and in Korea (Fig. 1).

The lead-zinc deposits and the copper deposits in both countries are very similar in their respective natures. The radiometric ages of these deposits and the related granitic rocks are in the range of 50–120 Ma in Japan (SHIBATA and ISHIHARA, 1973; NOZAWA, 1975) and 50–110 Ma in Korea (KIM, 1971; LEE and UEEDA, 1977; YUN and SILBERMAN, 1979), that is, the lead-zinc and copper deposits of both countries were formed approximately contemporaneously within the same metallogenic province.

It is also clear (see Fig. 1) that the regional lateral zones of ore deposits in Japan are offset southward relative to their counterparts in Korea. Judged from the similarity in the natures and ages of formation of the ore deposits in both countries, this offset must result from the southward drifting of the Japanese Islands relative to the Asiatic continent.

Although southward or southeastward drifting of the Japanese Islands is estimated from some other geological and geophysical data (for examples HORIKOSHI, 1972; UEEDA and MIYASHIRO, 1974; TATEIWA, 1976), it is clearly indicated by the displacement of the regional zones of ore deposits. The Japan Sea began to form about 50 Ma ago after the formation of these lead-zinc and copper deposits. SILLITOE (1977) suggested similar southward drifting of the Japanese Islands in early Tertiary time based on the distribution pattern of Pb–Zn and Cu–W deposits in Japan and Korea.

According to the data available, the Sikhote-Alin Province, Siberia, U.S.S.R., may belong to the lead-zinc zone, and the age of the granitic activity closely associated with the mineralization is reported to be 50–80 Ma peaking at 60 Ma (OTSUKI and EHIRO, 1978). This age range is very similar to that of the granitic activity of Japan and Korea.

From these data, the paleogeography of the Far East in early Tertiary time about 50 Ma ago can be restored as shown in Fig. 2. The approximate position of the early Tertiary trench is also shown in Fig. 2. At that time, the Sikhote-Alin Province, the Japan Sea side of Japan and the northern half of Korea constituted the same metallogenic province of lead-zinc deposits, and the Pacific Ocean side of Japan and the southern half of Korea the same metallogenic province of copper deposits. In other words, an approximately complete regional lateral zoning of lead-zinc and copper deposits existed in the area at that time.

Of course, there is a transitional zone between the lead-zinc zone and the copper zone. The ore deposits of the Tsumo and Akenobe mines (Fig. 1 and Table 1) occur within this zone. In these deposits, the vertical zoning of lead, zinc and copper ores is well observed.
2. Regional lateral zoning of the ore deposits in Southeast China

The available data on this subject in China are few. Many contact-metasomatic deposits are known on the lower course of the Yangtze River, some of them being under active exploitation. They are mostly the copper deposits with subordinate amounts of lead-zinc ores (Kuo et al., 1977). Accordingly, this area may belong essentially to a copper zone. Lately, many porphyry copper deposits of large size have been discovered in Southeast China, some of them being under active exploitation now.

According to the latest data available (ARGALL, 1979a, b; WYLLIE and PAZOUR, 1979; GUO*1 et al., 1982b), it is almost sure that a regional lateral zoning of the Mesozoic endogenic lead-zinc and copper deposits is present in the area south of the Yangtze River in China. The lead-zinc deposits occupy the western part of the area and the copper deposits the eastern part (Fig. 3).

The radiometric age of the granitic rocks closely associated with the formation of the ore deposits south of the Yangtze River is in the range of 190 to 140 Ma (Kuo et al., 1977; GUO*1 et al., 1982a, b); that is, the main stages of mineralization belong to the Jurassic early Yenshanian epoch, which corresponds to the Daebo epoch of Korea. Thus, the Chinese deposits are somewhat older than the deposits of the Korea-Japan-Sikhote Alin Province already mentioned.

The position of a Mesozoic trench in the area is not exactly ascertainable, but such a trench might be approximately coextensive with the late Cretaceous to early Tertiary trench of the Korea-Japan-Sikhote Alin Province. If so, the regional extent of the copper zone becomes very large. As will be stated later, this large extent may have a close relation to the small inclination of the subduction zone in Mesozoic time.

3. Regional lateral zoning of the ore deposits in Southeast Asia

The available data on this subject are sparse. According to NHAN (1981), lead-zinc mineralization was more prevalent than copper mineralization in Vietnam throughout Mesozoic time. In the writer's opinion, the lead-zinc mineralization may indicate a zone corresponding to the southwest extension of the lead-zinc zone of Southeast China already mentioned.

The Philippines may have belonged to the copper zone paired with the lead-zinc zone of Vietnam at that time, because the Philippines constituted the marginal area of the Asiatic continent before the formation of the South China Sea. According to WOLFE (1981), the South China Sea began to open in the Oligocene, and the Philippines began to drift eastward until they arrived at their present position above a westerly dipping subduction zone.

The border zone between Burma and Thailand may belong to the lead-zinc zone, judging from the occurrence of a large Mesozoic lead-zinc deposit at Pha Daeng
Fig. 4 Regional lateral zoning of the Mesozoic to early Tertiary endogenic Pb-Zn and Cu deposits in East Asia.

about 500 km northwest of Bangkok, Thailand (TANTISUKRIT, 1978), but no extensive copper zone is known in the area west of the border zone.

In the Malayan Peninsula, the prospecting of the Mesozoic lead-zinc deposits is more strongly emphasized than that of copper deposits (TAN and KHOO, 1978). In Sumatra, a mixed occurrence of copper deposits and lead-zinc deposits of late Mesozoic to early Tertiary age is reported (DJUMHANI, 1981). Though it may be bold, Fig. 4 can be drawn to summarize the data so far given.

Discussion and Conclusions

On the basis of the facts so far stated, some discussion of the mechanism of formation of the regional lateral zoning of the Mesozoic to early Tertiary lead-zinc and copper deposits in East Asia, as well as of the origin of the ore-forming elements in the deposits, will be given.

Throughout Jurassic to early Tertiary time, the oceanic plate was continuously subducting under the East Asian continental plate, inclined approximately northwest in the Far East. In the writer's opinion, deformation of the continental plate due to subduction of the oceanic plate was the principal cause of the formation of lateral zoning of the ore deposits of the whole region.

The thickness of the continental crust of the region during that time was estimated to have been fairly large—perhaps 50 km of more, judging from the thickness or the present continental crust of Southeast China (GUO et al., 1982a; CUMMING and SHILLER, 1971). The temperature around this depth (the Mohorovičić discontinuity) was estimated to have been 600–700°C (CLARK and RINGWOOD, 1964).

As the result of this orogenic movement, the area under consideration was upheaved, the stress field became extensional and fracturing took place within the stressed continental plate. Water released from the subducting oceanic crustal materials including the pelagic sediments by their dehydration was added to this fractured portion to help its melting. The effect is shown schematically in Fig 5.

We have no ample data on the abundance of ore-forming elements such as Cu, Pb and Zn in the source rocks within the continental plate from which the ore-forming magma originated in this region during Mesozoic to early Tertiary time, but we may be sure that the upper portion of the plate contained more lead and zinc and less copper than its lower portion. As is well known, copper is more abundant than lead and zinc in gabbroic rocks, whereas lead and zinc are more abundant than copper in granitic rocks. From the tables of RANKAMA and SAHAMA (1950), the Cu/Pb+Zn ratio is calculated to be about 1.5 in some gabbroic rocks, whereas the Pb+Zn/Cu ratio is about 10–14 in some granitic rocks. And from the tables of TUREKIAN and WEDEPOHL (1961), the Pb+Zn/Cu ratio is calculated to be 5.1, 1.3 and 5.8 in ultramafic, mafic and granitic rocks, respectively (Table 2).

Lately, the discovery of high grade copper or zinc sulfide deposits has been reported on
Regional lateral zoning of endogenic deposits

Fig. 5 Schematic diagrams showing the relation between the subduction of the oceanic plate and the regional lateral zoning of the endogenic deposits in the continental plate.
Ca: more acidic portion of the continental plate, Cb: more basic portion of the continental plate, O: oceanic plate, large circle: site of magma generation, small circle: site of magma consolidation.

Table 2. Concentration in ppm of copper, zinc and lead in igneous rocks (TUREKIAN and WEDEPohl, 1961).

<table>
<thead>
<tr>
<th>Metals</th>
<th>Ultramafic</th>
<th>Mafic</th>
<th>Granitic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu</td>
<td>10</td>
<td>87</td>
<td>10</td>
</tr>
<tr>
<td>Zn</td>
<td>50</td>
<td>105</td>
<td>39</td>
</tr>
<tr>
<td>Pb</td>
<td>1</td>
<td>6</td>
<td>19</td>
</tr>
</tbody>
</table>

the bottom of the Red Sea and the Mid-Ocean Ridges or Rises. Some of the deposits are very large, but the lead content is very small in all the deposits ever found (FRANCHETEAU et al., 1979; RONA, 1984). Considerable amounts (50-90 ppm) of copper and zinc are contained in the present oceanic basalts (LE ROEX et al., 1981), but the contribution of copper from the subducting oceanic plate or crust rich in copper to the magma formed within the continental plate might not be so conspicuous in any styles of transportation. If the contribution is conspicuous, then the proper explanation for the regional lateral zoning of ore deposits in this area becomes very difficult. From the same reason, the contribution of metallic elements such as lead and zinc from the subducting pelagic sediments might not be so conspicuous. We cannot explain this lateral zoning merely by the post-igneous action of magma generated from the subducting oceanic crust or plate by its partial melting, as stated by SILLITOE (1972).

It may, therefore, be concluded that the lead-zinc deposits and the copper deposits were formed in a close genetic connection with magma originating from the more acidic upper portion and the more basic lower portion of the continental plate, respectively. A scheme for accomplishing the regional lateral zoning of the lead-zinc and copper deposits now observed in the area is shown in Fig. 5. In it, in a rough way, the more acidic upper portion of the continental plate corresponds to the upper layer of crust, and the more basic lower portion corresponds to the lower layer of crust plus the uppermost portion of mantle.

The isotopic ratio of ore lead was studied in detail by SASAKI et al. (1982). According to them, most of late Mesozoic to early Tertiary ore lead in Japan originated from the continental crust. No data are available to discuss about the behavior of zinc contained in the subducting oceanic crust or plate and the more basic lower portion of the continental crust.

As can be understood from Fig. 5, the gentler the inclination of the subduction zone, the broader the copper zone tends to become. If so, the copper zone in Southeast China, already mentioned, may be one of the best examples of zone broadening in East Asia. The zone has a width of more than 500 km. Of course, the lead-zinc zone is correspondingly broadened. Other good examples are known on the opposite side of the Pacific Ocean.

In contrast, the extensive occurrence of ore deposits or the presence of a lot of large ore deposits cannot be expected within a continental plate paired with a subducting oceanic
plate having a very high inclination. The Burmese-Malayan peninsula and Sumatra may have been so related to a steeply dipping, subducting plate during Mesozoic time.

In conclusion, it can be said that a copper zone occupying the ocean side is flanked by a lead-zinc zone occupying the continental side in the East Asian area (Fig. 4). A similar relation is also known on the opposite side of the Pacific Ocean.

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東アジアにおける中生代～第三紀初期の鉛・亜鉛、
銅鉱床の広域的水平帯状分布とその地質的背景
付：日本列島移動の時期

宮 沢 俊 弥

要旨：東アジアの各地には、中生代～第三紀初期のものに花こう岩質マグマの活動に関接して生成された鉛・亜鉛鉱床と銅鉱床との広域的水平帯状分布が見られる。最も顕著なのは日・韓両国。次いで中国の東南部のものである。ソ連沿岸州の鉛・亜鉛鉱床は日・韓両国の鉛・亜鉛帯の東方の延長にあたるものと思われる。

この帯状分布をおこした最大の地質的背景の1つは海岸プレートのもぐり込みによる大陸プレートの変動である。上述の地質時代を通じ、海岸プレートはほとんどの試みの境界プレートの下にもぐり込んでいた。その結果、もぐり込みを受けた大陸プレートは押上げられ、変動を受け、その一部にマグマが発生し、これに密接に関連して鉛・亜鉛鉱床と銅鉱床が生成された。その際、鉛・亜鉛鉱床は大陸プレートの上部より酸性の部分に発生したマグマに、銅鉱床はその下部のより塩基性の部分に発生したマグマに関連して生成され、その結果両者の広域的水平帯状分布が生じた。銅帯は沿岸州の大陸プレートの縁辺部に位置し、鉛・亜鉛帯はこれをふちに取るようにその外側（大陸側）に位置する。この場合、海洋プレートのもぐり込みの角度が小さい場合ほど、それぞれの帯の幅が広大となったものと思われる。

日・韓両国における同時期の船・亜鉛帯と銅帯とのずれからみて、日本列島の南への相対的移動はこれらの帯の生成後、ほぼ5000万年前に開始されたものと思われる。